Traumatic Lateral Plantar Artery Pseudoaneurysm and the Use of Time-Resolved MR Angiography

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Abstract Vascular injury resulting in pseudoaneurysm formation in the plantar aspect of the foot is an uncommon injury after trauma. Such injuries are more often reported in the lateral plantar artery rather than the medial plantar artery, most likely because of its more superficial location. Traditional modalities in diagnosis have included ultrasound and digital subtraction angiography. We present a case of traumatic pseudoaneurysm of the lateral plantar artery following a foot laceration. Diagnosis was made by the use of high-resolution, time-resolved contrast-enhanced 3D magnetic resonance angiography, also referred to as “TRICKS” (time-resolved imaging of contrast kinetics). This technique provided high spatial resolution for the arterial anatomy as well as temporal resolution which allowed better delineation of the hemodynamic characteristics of the pseudoaneurysm.

Keywords magnetic resonance angiography · time-resolved imaging of contrast kinetics · TRICKS · plantar artery pseudoaneurysm

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Introduction

The term pseudoaneurysm or false aneurysm refers to the leakage of blood through an unhealed partial defect of the vessel wall, which is contained by the surrounding tissue forming a pseudocapsule [1]. Vascular injury resulting in pseudoaneurysm formation in the plantar aspect of the foot is uncommon, despite the potential for injury.

Lateral plantar artery pseudoaneurysms have been reported following plantar fasciotomy [2, 3], calcaneal osteotomy [4], and remote calcaneal fracture [1]. Following foot laceration, there are a few cases of lateral plantar artery pseudoaneurysm reported in children [5, 6]. Pseudoaneurysms of the medial plantar artery are less commonly encountered but have been documented following percutaneous pinning for Lisfranc fracture–dislocation [7].

We present a case of traumatic pseudoaneurysm of the lateral plantar artery following a laceration of the foot. Diagnosis of the pseudoaneurysm was made by routine magnetic resonance (MR) imaging of the foot, followed by high-resolution, time-resolved contrast-enhanced 3D MR angiography. This magnetic resonance angiographic technique, also referred to as “TRICKS” (time-resolved imaging of contrast kinetics), provided not only high spatial resolution for arterial anatomy, but also temporal resolution which allowed better delineation of the early filling and delayed washout characteristics of the pseudoaneurysm.

Case report

The patient is a 26-year-old male who, 2.5 weeks prior to his referral, stepped on glass stemware. The glass stem punctured his sandal, entered his foot in the heel region, and created a 1 cm wound. The patient removed the glass and reported a large amount of pulsatile bleeding. Hemostasis was achieved at the emergency room of an outside institution, and no foreign bodies were identified within the wound on physical examination or radiographs. MR

imaging from an outside institution reported an “artifact” within the area of injury. Upon presentation to our institution 2 weeks following injury, the physical examination revealed pain along the plantar fascia made worse by stretching. There was no frank Tinel’s sign and no decrease in plantar sensation. He denied any constitutional symptoms. There were no clinical signs of infection. An ultrasound examination was performed over the puncture site utilizing an IU22 ultrasound system (Phillips Medical, Bothell, WA, USA) with a 12 and 17 MHz transducer linear phased array demonstrating no foreign body.

Six weeks after the initial trauma, the patient returned with a 2-day history of “tingling, burning, shooting” pain in the ankle region. Physical examination was positive for pain along the plantar fascia with stretching, but now with a mild positive Tinel’s sign along the course of the tibial nerve. There was no erythema or constitutional symptoms to suggest infection.

Follow-up MR imaging of the ankle was performed at our institution with a 3.0 Tesla clinical imaging system (14.0 HDx, GE Healthcare, Milwaukee, WI, USA), using a receive-only quadrature knee coil. Morphologic imaging was performed using a fast inversion recovery sequence obtained in the sagittal plane. This was acquired with a repetition time (TR) of 6,500 ms, echo time (TE) of 14 ms, field of view (FOV) of 16 cm, matrix of 288×288 , and slice thickness of 3.5 cm with no gap, at one excitation and receiver bandwidth of 41.7 kHz over the entire frequency range. Fast spin echo imaging was performed in the sagittal, axial, and oblique coronal planes. These were acquired with TR of 4,000 to 6,500 ms; TE of 24–25 ms (effective); FOVs of 13 cm (oblique coronal), 14 cm (axial), and 16 cm (sagittal); matrix of 512×384 ; and slice thickness of 4.0 mm (oblique coronal), 3.3 mm (axial), and 3.5 mm (sagittal) with no gap, at one excitation. A wide receiver bandwidth of 62.5 kHz was utilized over the entire frequency range. A low signal mass was visualized along the medial margin of the calcaneal body, largely within the substance of the

quadratus plantae (Fig. 1a–c). Flow-related artifacts, typical of pseudoaneurysm, were seen including signal void from turbulent flow and pulsation artifact in the phase-encoding direction. Just medial to the lesion and 5 cm deep to the puncture wound on the skin, there was a retained foreign body (Fig. 2).

Time-resolved contrast-enhanced 3D MR angiography was performed with a FOV of 22.0×16.5 cm, matrix of 384×192 , and slice thickness of 1.2 mm, at one excitation and receiver bandwidth of 41.7 kHz over the entire frequency range, following the intravenous injection of 0.2 ml/kg of gadolinium (Omniscan, GE Health Care, Princeton, NJ, USA). TRICKS was performed in this same setting to confirm the pseudoaneurysm, as well as to establish vessel origin, extent of injury to the surrounding vasculature, and to evaluate distal perfusion. TRICKS confirmed the pseudoaneurysm arising from the lateral plantar artery (Fig. 3a–c; Animation 1), without additional areas of vascular injury. The lateral plantar artery continued distally completing the plantar arch. The medial plantar artery was unaffected.

The patient was taken to surgery shortly thereafter. A $1.2 \times 0.6 \times 0.5$ cm piece of glass was removed just deep to the abductor hallucis muscle. The pseudoaneurysm was also visualized, but poor delineation of the feeding vessel led to unsuccessful surgical attempts to tie off the pseudoaneurysm. Two follow-up ultrasound examinations were performed as short-term follow-up prior to a planned percutaneous transluminal embolization. The ultrasound at 3 weeks and MRI at 2 months demonstrated interval complete spontaneous thrombosis of the pseudoaneurysm (Figs. 4, 5, and 6; Animation 2).

Discussion

Arterial injury to the plantar aspect of the foot is often unrecognized. A complete arterial laceration can undergo complete thrombosis and occlusion with foot perfusion maintained by the well-developed collateral system. How-

Fig. 1. Oblique coronal (a), axial (b), and sagittal (c) fast spin echo MR images of the ankle demonstrate a $3.3 \times 3 \times 2$ cm low signal intensity mass (arrows) along the medial aspect of the calcaneal body, mostly within the substance of the quadratus plantae muscle. The mass

exhibits flow-related artifacts, including signal void from turbulent flow and pulsation artifact in the phase-encoding direction (arrow head), suspicious for a pseudoaneurysm

Fig. 2. Oblique coronal fast spin echo MR image of the ankle demonstrates a triangular 1.0×0.5 cm low signal intensity foreign body (arrow) medial to the base of the lesion, later confirmed to represent a retained glass fragment

ever, in the setting of a partial arterial laceration, a clot and hematoma can initially form at the defect. If flow is reestablished and the hematoma and arterial lumen are continuous, a pseudoaneurysm can form. The outer wall of the pseudocapsule is composed of organized, fibrous hematoma which lacks the tensile strength of the native artery leading to growth and potential rupture [8].

The posterior tibial artery is located posterior to the medial malleolus, bifurcating into the medial and lateral plantar arteries. The lateral plantar artery is larger than the medial and can be considered an anatomic continuation of posterior tibial artery [9]. The lateral plantar artery passes

laterally under the proximal abductor hallucis and flexor digitorum brevis muscles, coursing along the lateral margin of the flexor digitorum brevis, where it is superficially located below the plantar fascia. The medial plantar artery remains deep and is protected by the abductor hallucis, flexor hallucis longus, and quadratus plantae muscles. It is postulated that the more superficial location of the lateral plantar artery will account for its higher risk of injury [5].

Conventional MR angiography has proven to be an excellent modality for evaluating peripheral arterial vascular disease, with comparable sensitivity and specificity to digital subtraction angiography (DSA) [10, 11]; however, some limitations are inherent. Appropriate bolus timing is required from intravenous contrast injection to image acquisition. Too early an acquisition will result in less than ideal arterial enhancement. Too late an acquisition will lead to venous contamination. Unequal distribution of atherosclerotic disease may result in differential filling of the arterial segments [12, 13]. Conventional MR angiographic images also represent a single moment in time, providing little information on flow dynamics or tissue enhancement. In the trauma setting, computed tomographic angiography (CT-A) acquired during multiple phases of contrast enhancement can provide dynamic information [14]. However, the benefits of multiple CT acquisitions are counterbalanced by the potentially unnecessary radiation exposure.

Time-resolved contrast-enhanced 3D MR angiography is a commercially available method of data acquisition which eliminates the need for bolus-chase techniques. This pulse sequence has the ability to acquire images through a volume of tissue throughout the passage of a single contrast bolus [13]. This ensures the acquisition of images which demonstrate the peak level of arterial

Fig. 3. Arterial phase (a, b) and venous phase (c) time-resolved contrast-enhanced 3D MR angiography demonstrates rapid contrast filling and delayed washout of a pseudoaneurysm (arrow) of the lateral plantar artery (iv), 3 cm distal to the bifurcation of the posterior

tibial artery (ii). The lateral plantar artery continued distally beyond the pseudoaneurysm to complete the plantar arch. (i) Anterior tibial artery, (ii) posterior tibial artery, (iii) medial plantar artery, (iv) lateral plantar artery, and (v) distal fibular arteries [21]

Fig. 4. Power Doppler ultrasound at 3 weeks follow-up demonstrates no blood flow within the hypoechoic pseudoaneurysm, indicating complete thrombosis

enhancement, while maintaining high sensitivity and specificity for arterial occlusive disease that is comparable to DSA [12, 15, 16]. In addition, information obtained from the bolus transit time can indirectly reflect flow rate. In the setting of vascular injury, active arterial extravasation, arterial pseudoaneurysm, and arterio-venous fistula can all be distinguished by their dynamic flow enhancement characteristics over time [14].

Untreated, progressive enlargement of the pseudoaneurysm can lead to nerve and vessel compromise, ulcer formation, and ultimately rupture [8]. Because of the foot's collateral circulation, proximal and distal ligation of the vessel ends should be effective therapy and obviate the need for vascular reconstruction [5]. Other effective therapies have included transluminal coil embolization or ultrasound-guided injection of thrombin directly into the pseudoaneurysm [7].

Fig. 5. Sagittal fast spin MR image of the ankle at 2 months follow-up demonstrates high signal intensity within the pseudoaneurysm (arrow), without flow-related signal voids or pulsation artifact, indicating complete thrombosis

Fig. 6. TRICKS MR angiography at 2 months follow-up demonstrates diminished flow within the lateral plantar artery and the complete lack of contrast filling of the pseudoaneurysm, indicating complete thrombosis. (i) Anterior tibial artery, (ii) posterior tibial artery, (iii) medial plantar artery, (iv) lateral plantar artery, and (v) distal fibular arteries

In our case of traumatic pseudoaneurysm, TRICKS in combination with standard high-resolution MR imaging was integral in patient care. While the use of ultrasound is well established in evaluating foreign bodies in the extremities [17], the initial “false negative” result was likely related to the depth of the glass fragment from the skin puncture wound. The non-visualization of the pseudoaneurysm on this initial ultrasound, may be attributable to the evolving nature of the lesion. It is hypothesized that in this case, the development and growth of the pseudoaneurysm was responsible for the worsening symptoms and the subsequent development of a positive Tinel’s sign at the follow-up appointment. Migration of the foreign body was also a potential contributing factor. While the pseudoaneurysm could be implied by its flow-related artifact on the conventional MRI, the addition of TRICKS provided confirmation of this diagnosis, as well as detailed information regarding vascular anatomy, tissue perfusion, and surgical planning.

In conclusion, time-resolved contrast-enhanced 3D MR angiography is an accurate and effective modality in evaluating vascular pathology in the extremities. Its use in peripheral arterial occlusive disease has compared favorably to the DSA, and it can play an important role in the planning of percutaneous or surgical interventions [12, 13, 15, 16, 18]. In our report, we present a case that expanded the role of TRICKS to evaluate one form of vascular injury. Further uses of this technique can include any disease pathology in which the assessment of the degree of synovial perfusion and capillary permeability is needed. In particular, dynamic contrast-enhanced MRI measurements have been used in rheumatoid arthritis to measure the degree of acute inflammation, predict erosive progression, and evaluate response to treatment [19, 20].

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